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First test of the electrostatic deflectors to be used for beam-beam separation in LSS4 and LSS5

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1. Introduction

A horizontal and a vertical electrostatic deflector, consisting of two units each, have been installed in the SPS for the separation of the proton and antiproton beams in LSS4 and LSS5. A step-wise separation will permit to measure the luminosity in the interaction points according to a method first proposed for the ISR by S. van der Meer (1) and extended to the case of the $p\bar{p}$ collider by C. Rubbia (2): The event rate in a counter telescope looking at the interaction region is observed as a function of the distances by which the beams are separated in the horizontal and vertical planes.

With just one deflector in each plane the proton and antiproton orbits are affected all around the SPS. Even if the beams are completely separated in LSS4 and LSS5, they will partially overlap in other crossing points and adverse effects due to non-linear beam-beam forces cannot be excluded. In order to distinguish such effects from others which might result from the closed orbit deformation or from the (weak) non-linear components of the electrostatic field, it seemed important to make tests with a single beam before using the deflectors for beam-beam separation.

The results of a first test with a proton beam will be reported in this note after a description of the deflector system and its planned utilization.

2. Short description of the deflector system

The four deflector units are installed in LSS5 upstream of QD 517. Fig. 1 shows a schematic view of the layout and the high voltage circuit of the horizontal and vertical deflectors, called ZDH and ZDV respectively. Fig. 2 shows a cross-section of ZDH.

A deflector unit consists of a pair of Titanium plates, 3 m long and 160 mm wide each, which are mounted in a vacuum tank. The distance of each plate from the SPS centre line can be remotely adjusted in the range from 10 to 80 mm. The distance between the two plates can thus be varied between 20 and 160 mm. One of the Titanium plates is kept at ground potential whereas the second plate can be charged to a negative high voltage which may reach - 300 kV. The operational voltage should, however, not exceed - 250 kV in order to leave sufficient margin with respect to the limit of conditioning. The high voltage on both deflectors, ZDH and ZDV, can be measured precisely, using a resistive comparator which may be connected to either of the deflectors with the help of a high voltage commutator.

After their use the deflectors can be switched off rapidly by activating earth switches which short-circuit the high voltage to ground.

Protons are deflected outwards and upwards by the horizontal and vertical separators respectively.

3. Expected high-voltage performance of the deflectors

One of the major problems which may arise when using the deflectors, is sparking between the Titanium electrodes. Sparks are mainly initiated by ions which are created by the circulating beams and accelerated in the high electric field towards the cathode. A spark in one of the deflector units leads to a sudden breakdown of the field and is thus felt by the proton and antiproton bunches as a kick. The final result after filamentation will be increased beam emittances and a correspondingly lower luminosity. The sparking rate must therefore be kept so low that the probability of a spark during a two dimensional van der Meer scan remains small.

The sparking rate critically depends on the electrode material, the strength of the electric field between the electrodes, the vacuum in the deflector tanks and the total intensity of the p and $\bar{p}$ beams. In an environment where ions are created by a circulating beam, Titanium has proved to be by far the best electrode material and has therefore been chosen for the $p\bar{p}$ deflectors in spite of its high cost. The deflectors were installed in a region of particularly low vacuum pressure near the interaction point in LSS5 which permits more easily to reach the required high vacuum in the deflector tanks. Without the sublimation pumps a pressure of some 4×10^{-10} Torr has been reached so far and there is good hope to lower this pressure by more than a factor of two in the near future. With a nominal field strength of 50 kV/cm and a circulating beam intensity of about 1×10^{12} particles the complete deflector system is then supposed to spark at most 3 times within 24 hours. This sparking rate which looks tolerable was estimated following extensive tests, in the laboratory and in the SPS, of a prototype deflector.

4. Planned utilization of the deflector system

The design of the electrostatic deflectors was based on a field strength of 50 kV/cm. Two units of 3 m length then deflect a beam at 270 GeV/c by 0.11 mrad. At a position P of the SPS circumference this deflection angle ϑ leads to the following separation ΔS between proton and anti-proton trajectories:

$$\Delta S = \vartheta \times \sqrt{\beta_{DEFL.}} \times \sqrt{\beta_p} \times \left| (\sin \pi Q)^{-1} \times F \right|$$

with

$$F = \cos \left[(\psi_p - \psi_{DEFL.}) - \pi \times (Q-n) \right]; \quad Q-1 < n < Q$$

It is obvious that the separation obtained at a given position P strongly depends on the machine tune Q and on the phase shift between the deflector and P. For constant Q this phase shift still varies with the adjustment of the low-β insertions.

At the time when the lattice positions of the horizontal and vertical deflectors had to be fixed, it was not clear which SPS configuration (tune + low-β values in LSS4 and LSS5) would be used for $p\bar{p}$ operation. (Even now it probably still needs hard work before an optimum configuration is found.) It was therefore decided to choose deflector positions which offer practical advantages, such as high vacuum environment, short connections to the high-voltage generators in the auxiliary building etc. This lead to the installation of both deflectors upstream of QD 517 as mentioned above.

Clearly, if we wish to separate the beams horizontally and vertically in both LSS4 and LSS5, by a sufficient amount ($\geq 8\sigma$), an adequate SPS configuration must be chosen. Such configurations exist, for instance the configuration $\{Q_H = 26.62;\ Q_V = 28.58;\ \beta_H \times \beta_V = 2 \times 1$ in LSS4 and LSS5$\}$, but it is unlikely that any of these coincides with what will turn out to be the preferred configuration for $p\bar{p}$ runs. Hence, a special adjustment of the SPS will be required for luminosity measurements based on beam-beam separation. We should remember, however, that these measurements essentially serve to calibrate the counter telescopes which continuously survey the luminosity. Re-calibration should not be needed too frequently and the disadvantage of a special SPS configuration, which could not be avoided anyway, does not seem a serious drawback.

5. Procedure and results of the first test with a proton beam

The aim of this first test was to verify the correct functioning of the electrostatic deflectors under operational conditions and to confirm that no noticeable adverse effects on a single beam are caused by the electrostatic field or the resulting orbit deformation, as long as the deflectors do not spark.

The procedure was as follows: 20 proton bunches (total intensity about 3×10^{11} protons) were accelerated to 270 GeV/c and stored. Machine tunes, closed orbits and beam profiles were measured in both, the horizontal and vertical plane. The distance between the Titanium electrodes of the deflectors was then reduced from 160 mm to 40 mm in all four units. After having observed that this aperture reduction had no visible influence on the beam lifetime, the voltage across the 40 mm gap was raised to 200 kV, first in ZDH, thereafter in ZDV, thus setting the field in the deflectors to its nominal value of 50 kV/cm. The resulting closed orbit deformations were measured, more beam profile scans were made (using the wire scanners in LSS2) and the proton intensity given by a BCT was observed.

During the test four coasts were made of a total duration of somewhat more than two hours, the longest coast lasting about an hour. Before interrupting a coast, sparks were provoked in either ZDH or ZDV by raising the high voltage to the present limit of conditioning ($\sim$ 250 kV). Beam profiles were measured before and after the sparking, showing the effect of one or several (up to 6) sparks on the beam emittance.

The results of the different observations and measurements can be summarized as follows:

- Within the accuracy of the measurement with the transverse pick-up stations, the agreement between calculated and measured orbit deformations due to the electrostatic deflection was very good. This was immediately obvious in the vertical plane, whereas in the horizontal plane a displacement of the mean radial position by about 2.1 mm was superimposed on the predicted modification. The beam had been slightly decelerated, since the deflection by ZDH produced an effect at the location of the radial loop pick-up. Fortunately, in $p\bar{p}$ collider mode the radial RF loop is not used. Beam-beam separation will therefore not suffer from its action, which would have led to complicated interferences.

Figs. 3 and 4 show vertical orbits measured with ZDV off and ZDV on at 50 kV/cm, respectively. With a vertical tune of 26.695 and $\beta_V \approx$ 78 m at the position of the deflector, a maximum orbit deviation of 6.3 mm is calculated, compared with an average of 6.2 mm measured by the pick-up stations near the lattice positions where the relative maxima coincide with β_{Vmax} (PU's near LSS2). The maximum orbit deviation in the horizontal plane was somewhat smaller, about 5.2 mm for a field strength of 50 kV/cm and Q_H = 26.715, due to the smaller β-value at the deflector position ($\beta_H \approx$ 47 m at ZDH).

- As long as there were no sparks in the deflectors, a degradation of the beam lifetime could not be observed.
- During the MD one non-provoked spark occurred in ZDH. This may be due to the fact that the conditioning of the deflectors is not yet perfect, but it may also be a simple random event. (Remember that the system was estimated to spark up to 3 times within 24 hours).
- Beam profiles measured before and after sparking reveal the disasterous effect of high-voltage break - throughs in the deflectors on the emittance of the coasting beam and later, in collider mode, on the luminosity. A single spark in one plane blew the emittance in that plane up by some 20 to 50%, depending on the initial emittance, and in the other plane by some 10 to 40% (due to coupling). A series of 6 consecutive sparks which was provoked once in the horizontal plane and, during another coast, in the vertical plane, led to an emittance blow-up by a factor of 4 in the plane concerned and by a factor of 2.3 in the second plane.

6. Conclusions

The first beam test of the electrostatic deflectors has shown that the hardware works well under operational conditions. The application programs which have been written for the remote control proved to be well adapted to the needs. No unexpected adverse effects on a single beam could be observed at the nominal strenght of the deflectors. After further high-voltage conditioning which is under way, their successful use for beam-beam separation can therefore be expected.

7. Acknowledgements

Many members of the SPS Division have contributed to the design, construction and installation of the deflectors. We would like to thank them all. In particular, we acknowledge the work of R. Guinand and M. Faure who took a major part in the design and of X. Altuna, R. Bonvin, R. Ducret, F. Merle, G. Paillard, A. Rizzo and J. Soubeyran who strongly contributed to the construction and installation.

8. References

(1) S. van der Meer; Calibration of the effective beam height in the ISR; ISR-PO/68-31.

(2) C. Rubbia; Measurement of the luminosity of $p\bar{p}$ collider with a (generalized) van der Meer method; CERN $p\bar{p}$ Note 28.

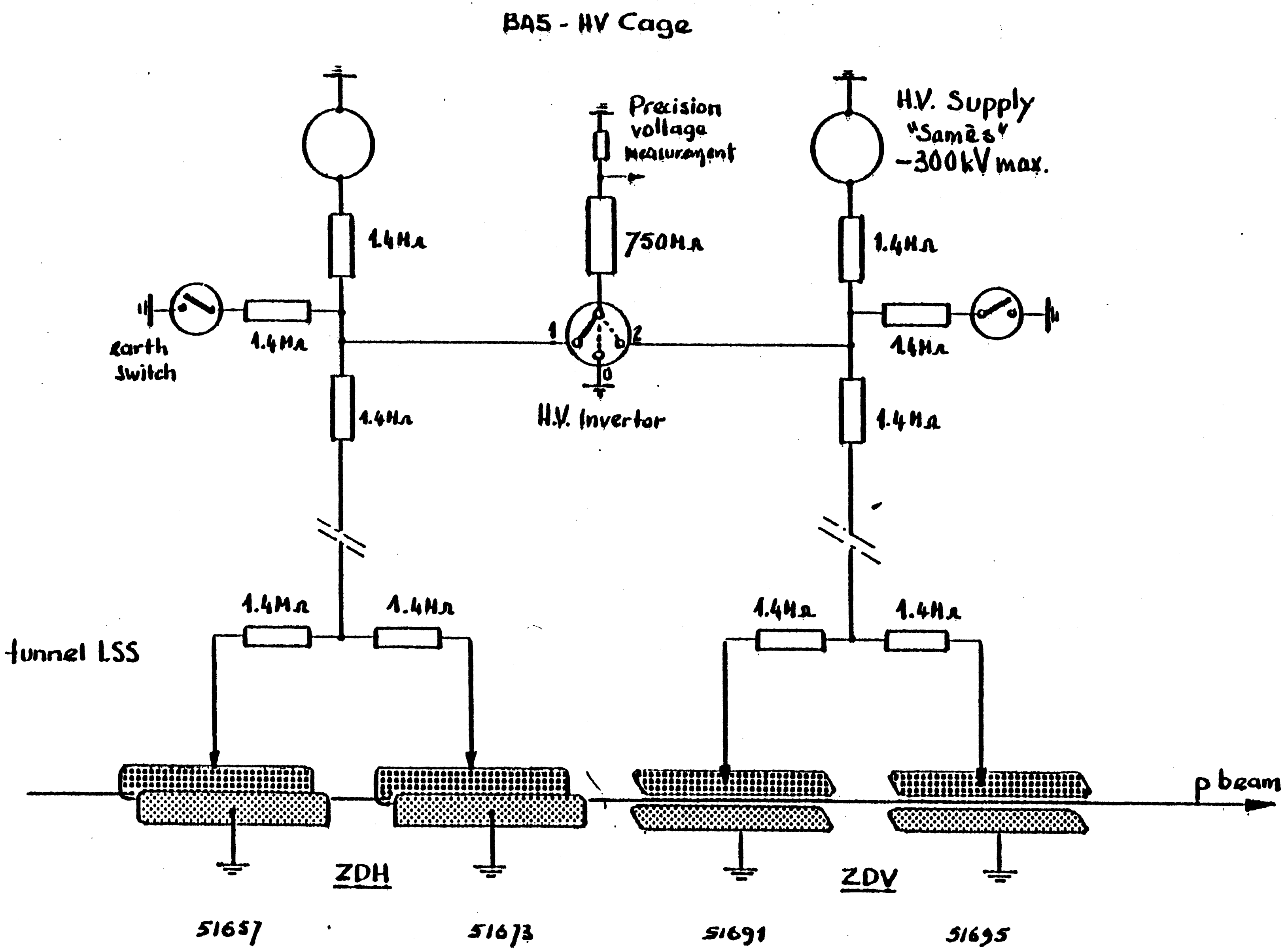

Fig. 1 - Schematic layout of the electrostatic deflectors and their high-voltage circuit.

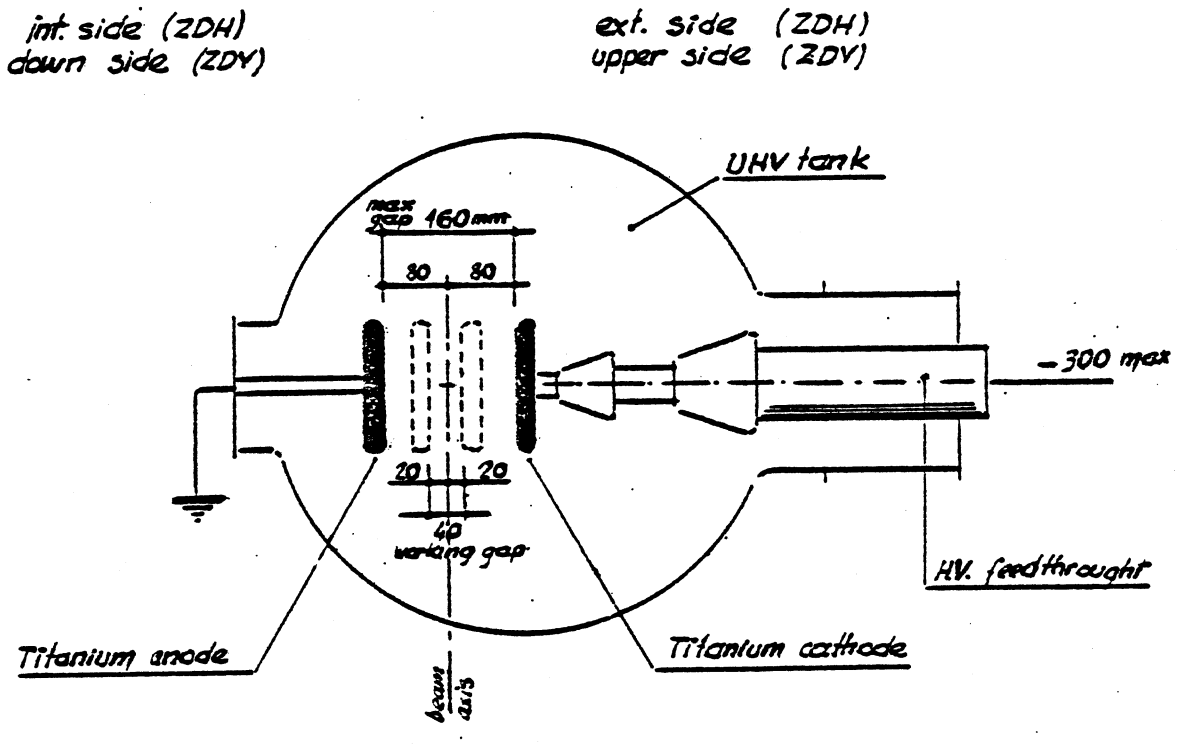

Fig. 2 - Cross-section of the horizontal deflector ZDH (schematic)

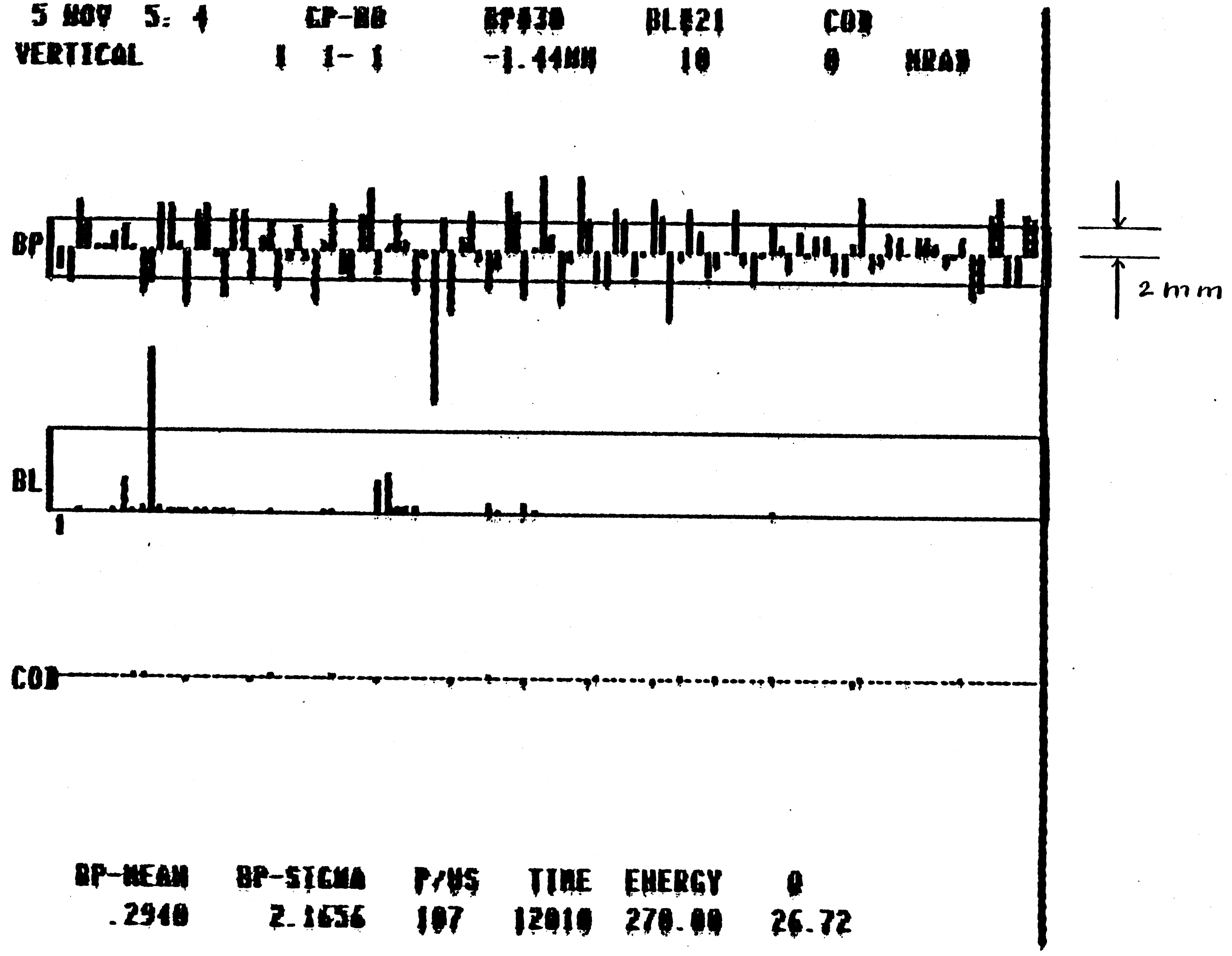

Fig. 3 - Vertical closed orbit at 270 GeV/c. ZDV off.

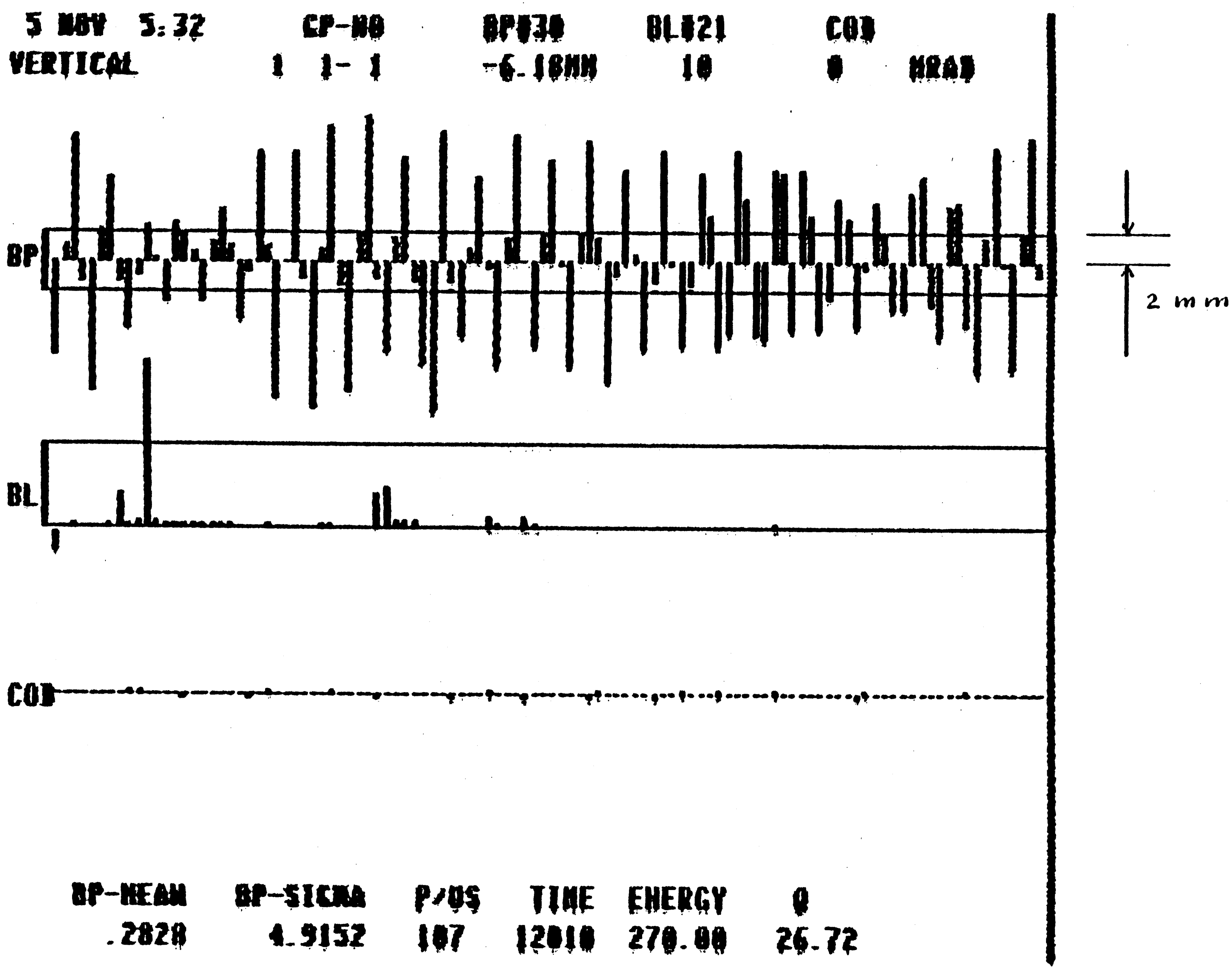

Fig. 4 - Vertical closed orbit at 270 GeV/c. Field strength of ZDV: 50 kV/cm